Coseismic Radon Changes of the 1995 Hyogo-ken Nanbu Earthquake

Masao Ohno* and Hiroshi Wakita

Laboratory for Earthquake Chemistry, Faculty of Science, The University of Tokyo,
Bunkyo-ku, Tokyo 113, Japan

This article reports a preliminary result of seismic-related radon changes in groundwater observed at a continuous monitoring station in the Tokai district. Immediately after the *M*7.2 Hyogo-ken Nanbu earthquake which occurred on January 17, 1995, the radon concentration of a water well at a hypocentral distance of 260 km decreased by about 5%. It is meaningful that a drop in the radon concentration was observed, while the water level showed no significant change.

1. Introduction

Earthquake-related changes in groundwater radon have been studied extensively. In Japan, universities and governmental agencies, including the University of Tokyo, have been carrying out continuous radon monitoring for about two decades. The most representative precursory radon change was that observed at SKE well in the Izu Peninsula for the *M*7.0 Izu-Oshima-kinkai earthquake on January 14, 1978 (Wakita *et al.*, 1980). In addition, numerous radon anomalies associated with earthquakes have been observed at KSM well in Fukushima Prefecture (Wakita *et al.*, 1989; Igarashi and Wakita, 1990; Igarashi *et al.*, 1993). Kodai and Takahashi (1992) also discussed changes of the radon concentration observed in the Tokai district in connection with deep earthquakes. These observations suggest that changes in groundwater radon reflect regional stress changes and, accordingly, can provide important information on earthquake occurrence.

On January 17, 1995, a disastrous *M*7.2 earthquake occurred in the southern part of Hyogo Prefecture in Japan. A number of geochemical and ground hydrological changes were observed associated with the earthquake. Increases of groundwater discharge were observed at many sites within the aftershock region. Among them, precursory changes were observed in groundwater at wells: those were changes in chloride ion concentration (Tsunogai and Wakita, 1995) and in radon (Igarashi

et al., 1995). Fujimori *et al.* (1995) reported an unusual increase in the discharge rate of groundwater in a tunnel section of the Rokko-Takao Station for crustal deformation observation that began more than 2 months before the main shock, despite the fact that this was the season of least precipitation and that the total rainfall in 1994 was extremely low. Ito *et al.* (1995) reported abnormal behaviors of mineral spring gases in central Japan, 220–230 km from the hypocenter, before and after the earthquake. In this paper we report the radon changes associated with the earthquake observed at an observation well 260 km from the hypocenter.

2. Observation

Continuous radon monitoring in the Tokai district started in 1977 (Wakita *et al.*, 1986). Two wells with depths of 150 m, RYO and YSD (Fig. 1), are located in alluvial plains close to large rivers, the Tenryuu and the Oi, respectively. A strainer, a perforated part of a casing pipe, is positioned at a depth of 84–101 m in RYO well and 127–145 m in YSD well. The radon concentration is measured by a ZnS(Ag) scintillation detector system (Noguchi and Wakita, 1977), and the water level is measured using a pressure transducer. Parameters causing background fluctuations in groundwater radon at these wells have been precisely discussed by Wakita *et al.* (1986). In brief, the variations in water level and radon of these wells are interfered with by heavy groundwater use in the area. Daily variations are significant in the observed hourly-mean values in

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* To whom correspondence should be addressed.

Fig. 1. Locations of two groundwater radon observation sites, RYO and YSD in the Tokai district (squares). The circle indicates the epicenter of the 1995 Hyogo-ken Nanbu earthquake.

Fig. 2. Variations in water level and radon concentration at RYO (upper) and YSD (lower) together with atmospheric pressure at RYO and precipitation at Hamamatsu (34.7°N, 137.7°E) in the period January 7–26, 1995. Thin lines are 1-h intervals and thick dotted lines are 25-h moving averages. The arrows indicate the occurrence of the 1995 Hyogo-ken Nanbu earthquake.

Fig. 3. Variations in water level and radon concentration at RYO (upper) and YSD (lower) together with precipitation at Hamamatsu between October 1994 and March 1995. Thin lines are 25-h moving averages and thick lines are 7-day moving averages. The arrows indicate the occurrence of the 1995 Hyogo-ken Nanbu earthquake.

Fig. 2, and tidal fluctuations are also significant. The 25-h moving averages of data (Fig. 3) show significant weekly variations. In addition, a large increase is noted during vacation seasons such as the New Year holidays. The daily and weekly variations of water level and radon are correlated negatively at RYO well and positively at YSD well.

A clear coseismic radon change associated with the Hyogo-ken Nanbu earthquake was observed at RYO well, located 260 km from the hypocenter. The radon decreased 5% right after the earthquake. We examined the raw data to find any sign of malfunction of the radon monitoring system due to the seismic wave vibration. No significant change was found either in the flow rate of the water or in

the water temperature in the radon detection chamber. The counting rate of the calibration alpha ray source, measured once a day, did not show any anomalous change either.

Figures 3 and 4 show the 25-h moving averages of radon data. It is obvious that the coseismic decrease in the radon level is significantly larger than the usual background fluctuations. The radon concentration level of RYO well increased gradually after the earthquake, and by June 1995 reached almost the same level as before the earthquake.

No significant change in water level of RYO well was observed in the hourly-mean value or in the 25-h moving average, as seen in Fig. 2. The well fluctuated only in response to the seismic wave of

Fig. 4. Long term variations in water level and radon concentration at RYO (upper) and YSD (lower) between September 1993 and August 1995. Lines are 25-h moving averages, and the arrows indicate the occurrence of the 1995 Hyogo-ken Nanbu earthquake.

earthquakes: about 40 cm in double amplitude was recorded at maximum on the recorder chart of the town office of Ryuyo.

In contrast, radon fluctuation due to the earthquake was not clear at YSD well, 300 km from the hypocenter of the earthquake. The radon dropped right after the earthquake but returned to the previous level within 3 days, as seen in Fig. 2. The water level did not show any change before and after the earthquake, as did that of RYO well.

3. Discussion

Since radon monitoring was begun in 1977 at RYO well, this was the first time a clear radon change was observed associated with an earthquake. According to Wakita *et al.* (1986), no meaningful changes were observed for earthquakes with $M \geq 6.9$ that occurred within a hypocentral distance

of 600 km or those with $M \geq 5$ that occurred within a hypocentral distance of 100 km in the period between 1977 and 1984. That is, no clear correlation was recognized between radon fluctuation and earthquakes. Neither was any coseismic radon change recognized in the period between 1985 and 1994. A future paper will investigate why radon anomalies appear for the $M7.2$ Hyogo-ken Nanbu earthquake.

A similar coseismic change in the flow rate of mineral spring gases at Byakko Spa, 220 km away from the epicenter, was reported by Ito *et al.* (1995). It is not easy to clarify the mechanism of those changes. Furthermore, the observed apparent radon decrease combined with no significant change in water level is contradictory. It is difficult to explain the present radon change in terms of a coseismic change in volumetric strain of the surrounding area,

because the change in volumetric strain may affect both the radon and water level.

4. Conclusion

A clear coseismic change was observed for the 1995 Hyogo-ken Nanbu earthquake at a radon observation station, 260 km from the hypocenter; it was the first observation of change during the last two decades of continuous radon monitoring at this station. It is meaningful that no coseismic change in water level was observed, in contrast to the change in radon. The changes give important information on the characteristic response of this well to earthquake occurrences, which in turn will provide a clue for geochemical earthquake prediction.

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